

Detection of an oscillatory phenomenon in optical transient counterpart of GRB090522C from observations on Peak Terskol

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Abstract

22 Sep 2005 Swift-BAT triggered and located GRB050922C. The light curve shows the intense broad peak with T_{90} of (5 ± 1) s. The Nordic Optical Telescope has obtained spectra of the afterglow with several absorption features corresponding to a redshift of $z = 2.17 \pm 0.03$. Observation of optical transient of GRB050922C was carried out in the R-band with the 60-cm telescope equipped with a CCD on Peak Terskol (North Caucasus). The OT magnitude was fading from $R \approx 16$ to ≈ 17.5 . Detection of an oscillatory phenomenon in the R post-burst light curve is described in this work. Analysis of the R data reveals coherent harmonic with a period of 0.0050 ± 0.0003 days (7.2 min) during observing run of about 0.05 days (~ 70 min). Amplitude of oscillations is about 0.05 magnitude. The simplest model suggests that GRB050922C may result from tidal disruption of a white dwarf star by a black hole of about one thousand solar mass. The periodicity in the light curve can be identified with relativistic precession of an accretion disc.

keywords gamma-rays: bursts – gamma-rays: theory – methods: statistical – black hole physics

1 Introduction

Gamma-ray burst GRB050922C was detected with satellites (Swift, HETE) and ground-based instruments. 22 Sep 2005 at 19:55:50 UT Swift-BAT triggered and located GRB050922C (Trigger = 156467). The light curve in Fig 1 shows the intense broad peak starting from $T - 3$ to $T + 3$ s with two sub-peaks on top. Ground-based instruments were able to measure an afterglow during a few hours both photometrically and spectrally. The Nordic Optical Telescope (La Palma) has obtained spectra of the afterglow [1]. It found several absorption features, including strong Lyman-alpha, OI+SiII, CII, SiIV, CIV, AlII and AlIII, corresponding to a redshift of $z = 2.17 \pm 0.03$. Assuming $z = 2.17$ and a standard cosmology model the isotropic energy release is $E_{iso} \sim 8 \cdot 10^{52}$ erg, the maximum luminosity is $(L_{iso})_{max} \sim 1.6 \cdot 10^{53}$ erg/s.

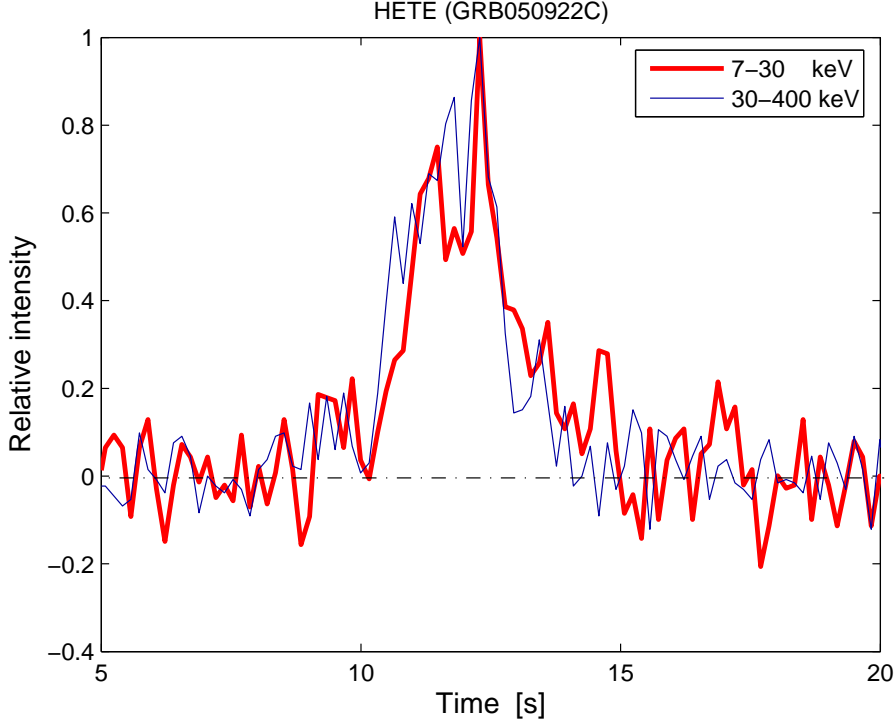


Figure 1: The GRB050922C light curve from HETE [3].

2 Observation of optical transient of GRB050922C

The ROTSE-IIID instrument at Turkey started ground-based observations of GRB 050922C afterglow at $T_{burst} + 172.4$ s ($T_{GCN} = 6.8$ s). It interrupted observations at 651 s due to precipitation. Observation of optical transient of GRB050922C were continued in the R-band with the 60-cm telescope equipped with a CCD camera on Peak Terskol (North Caucasus) starting Sep 22, 2005, 20:08:45 UT [2]. 61 images of 60 s exposure were taken between 20:08:45 and 21:18:20 UT. The OT magnitude was fading from $R \approx 16$ to ≈ 17.5 . Detection of an oscillatory phenomenon in the R post-burst light curve is described in this work.

3 Results

The original and resample equally spaced data are shown in Fig 2. We have used piecewise cubic spline interpolation to fill up a few gaps inside the primary data. High-frequency residuals after removing of polynomial trend are shown in Fig 3. The spectral analysis of residuals with the Tukey spectral window reveals clearly a harmonic with a period of 0.005 d = 7.2 min (Fig 4). The same result with the harmonic period of 0.0050 d demonstrates the wavelet power spectra in Fig 5. To make clear coherence features of this harmonic the reconstruction of a signal was performed using a continuous wavelet transform [5]. Digital filtering with the help of a continuous wavelet transform allows one to separate the non-stationary signal in an appropriate frequency range. This permits the oscillation to be analyzed separately. These results are shown in Fig 5. We may conclude that the GRB050922C light curve in the R band reveals coherent harmonic with a period of 0.0050 d (7.2 min) during observing run of about 0.05 d (~ 70 min). In Fig 7 a harmonic period of 0.0050 ± 0.0003 d follows from the maximum coordinates measurements shown in Fig 6. Amplitude of oscillations is about 0.05 mag and comparable with the internal accuracy of the photometry. Note both the windowed

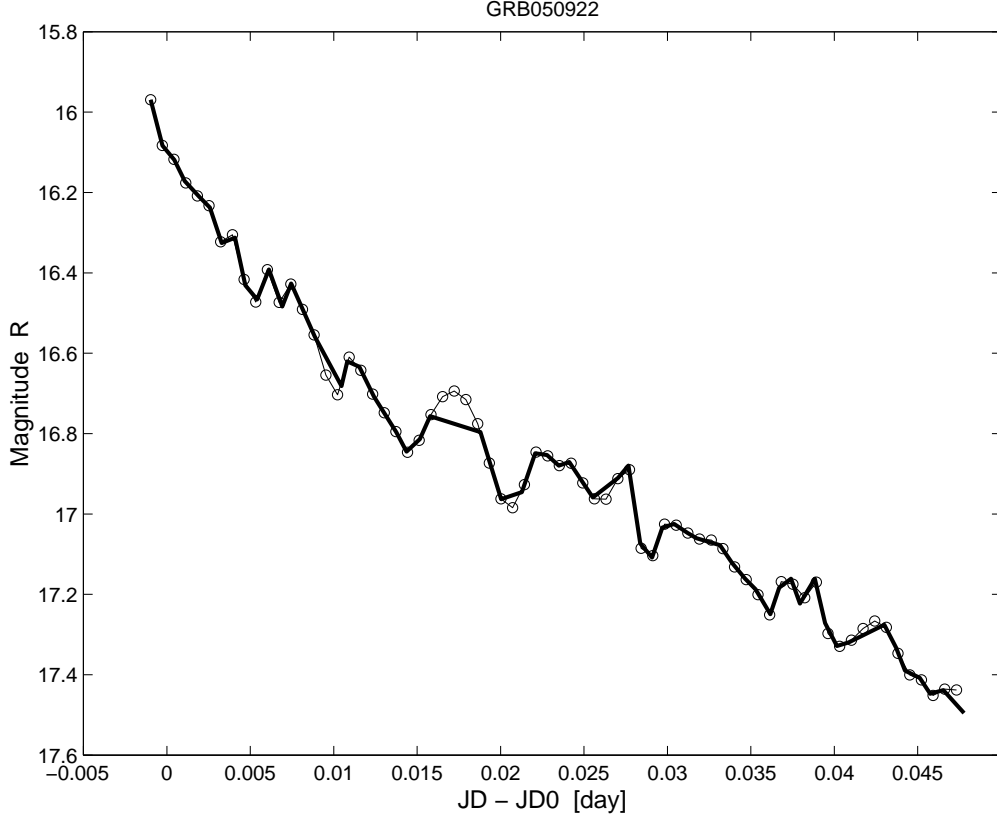


Figure 2: The original (the heavy curve) and resample equally spaced data (circles) to fill up a few gaps inside the primary data are shown.

and wavelet power spectra show coherent oscillation at the confidence level more than 99%.

4 Discussion

A luminous gamma/X-ray burst can occur when a star passes within the tidal radius of the massive black hole, and is disrupted. Disruption begins when the tidal acceleration due to the black hole equals to the self-gravity of the star. Light curve of the stellar debris is dependent both on the mass and spin of the black hole and disrupted star. The tidal disruption time scale is about of the free-fall time T_{ff} . This is the characteristic time it would take a body to collapse under its own gravitational attraction, if no other forces existed to oppose the collapse

$$T_{ff} = \frac{1}{4} \sqrt{\frac{3\pi}{2G\rho}} \quad (1)$$

Here ρ is the mean density. Note also that the free-fall timescale is practically coinciding with an oscillation period of a self-gravitating body

$$P \approx \sqrt{\frac{4\pi}{G\rho}} \quad (2)$$

Numerical calculation of the tidal disruption gives the estimate of the dynamical time of disruption close to above mentioned values, too [4]. For the Sun $T_{ff} = 1.78 \cdot 10^3 \text{ s} = 29.7 \text{ min}$; for a red dwarf of M5 V class $T_{ff} = 685 \text{ s} = 11.8 \text{ min}$; for a white dwarf and a neutron star of the solar mass $T_{ff} = 1.78 \text{ s}$ and $\approx 0.0001 = 0.1$

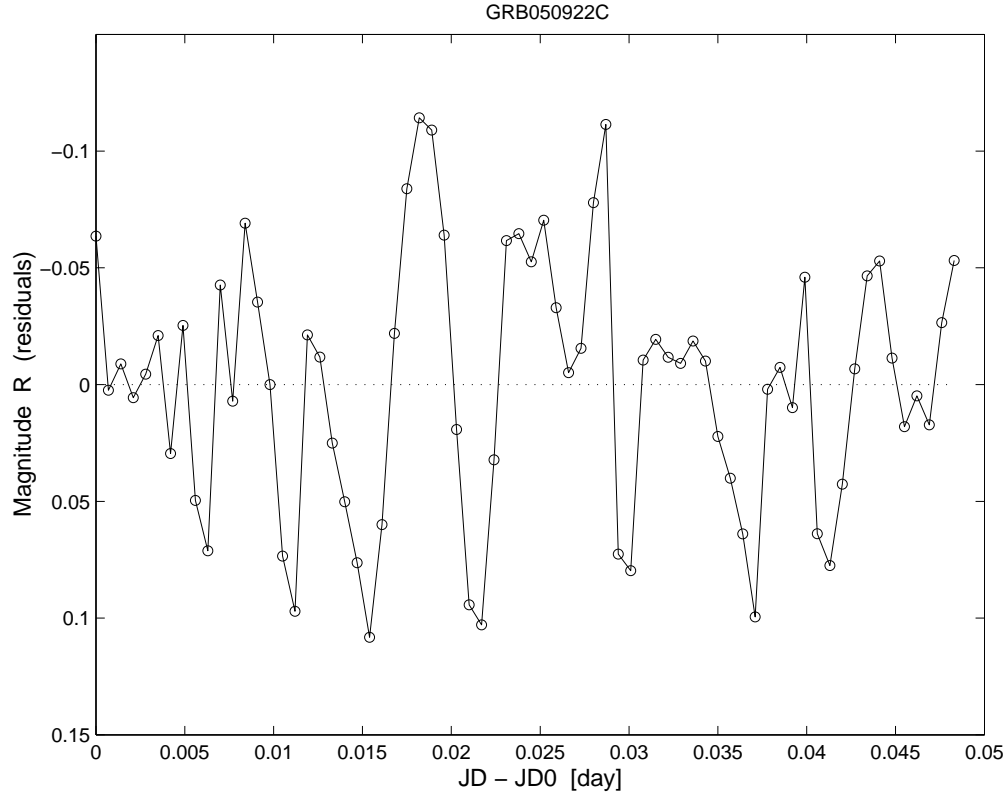


Figure 3: High-frequency residuals after removing of polynomial trend.

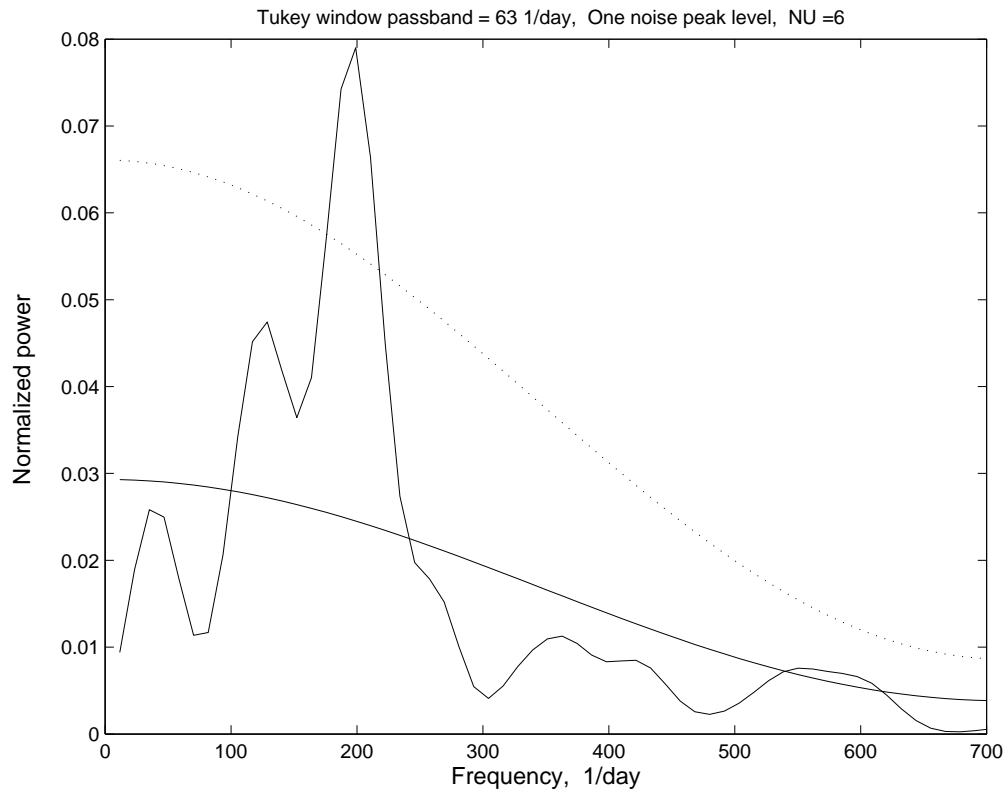


Figure 4: The power spectrum of residuals with the Tukey spectral window reveals clearly a harmonic with a period of $0.005 \text{ d} = 7.2 \text{ min}$. The dotted line corresponds to the 99% confidence for noise peaks.

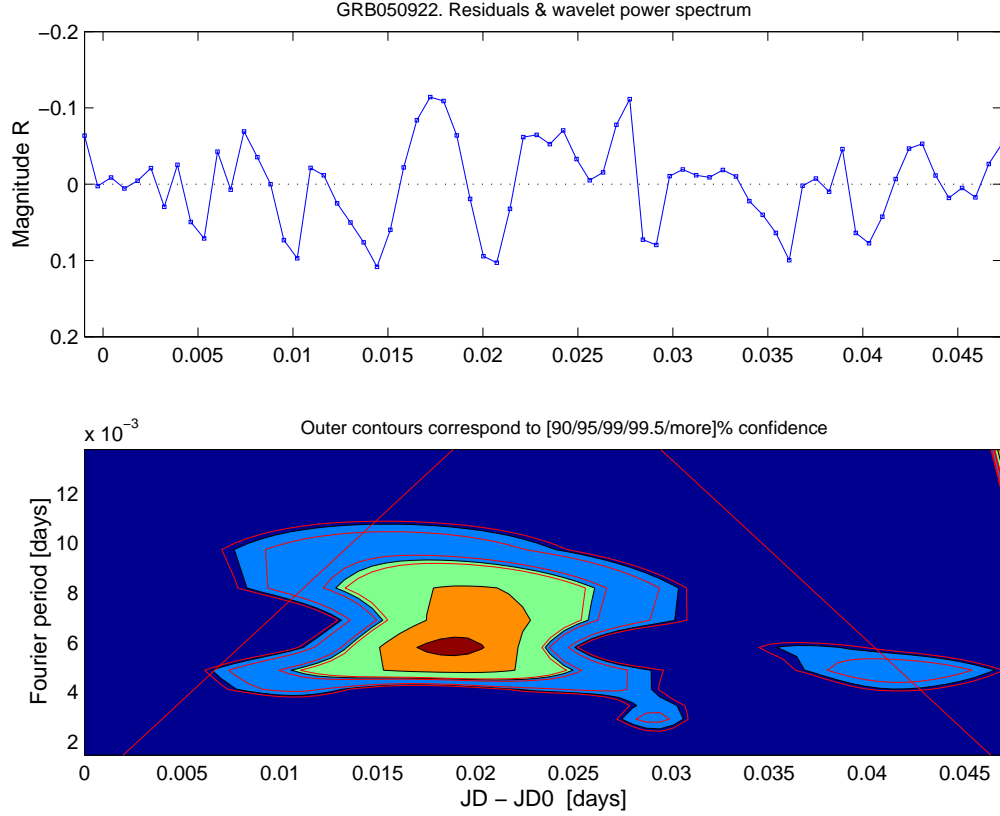


Figure 5: High-frequency residuals (top panel) and their wavelet power spectrum (bottom panel). The outer contours correspond to 90% and more confidence. A harmonic period is of 0.0050 d. The solid lines represent the cone of influence in the wavelet diagram where edge effects become important. We apply the wavelet transform following the approach laid out by Torrence & Compo [5].

ms, respectively. Really we can suppose that GRB050922C, bearing in the mind the above estimate of T_{ff} , results from tidal disruption of a white dwarf star by a black hole. Postdisruption behavior concerns formation of an accretion torus around the BH.

5 The tidal disruption of a white dwarf by a massive black hole

The pericentric distance at disruption is [4]

$$R_p \approx R_{star}(M_{BH}/M_{star})^{1/3} \quad (3)$$

The tidal disruption radius for a white dwarf (WD) of the solar mass and radius of $0.01 R_\odot$ depending on the black hole mass is shown in Fig 8. The pericentric distance is in the r_g units, where $r_g = 2GM_{BH}/c^2$ - the gravitational radius of a black hole. If the BH mass is $\geq 10^{38}$ g WD plunges in BH without disruption. So we may assert that in our case the BH mass is no more than 10^5 solar mass. From the tidal disruption condition (3) for the Keplerian period of disrupted star we have

$$P^2 = 4\pi/GM_{BH}R_p^3 \quad (4)$$

From Eq (3) for R_p after some algebra we have also

$$P^2 = 4\pi/GM_{star}R_{star}^3 \quad (5)$$

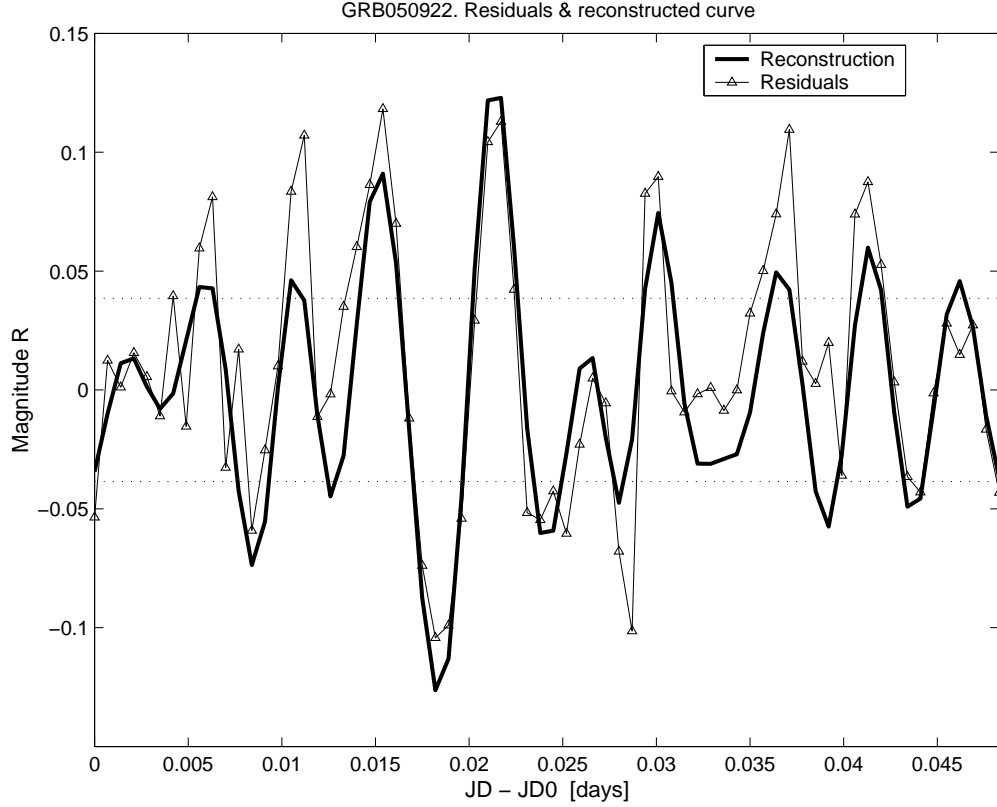


Figure 6: The reconstructed signal (the heavy curve) and raw data. The 2-sigma error corridor is shown as the dotted lines.

Thus, Keplerian period at the moment of disruption is independent of the BH mass. It depends only on the mass and radius of the star itself. We can sum up the main findings as follows:

- The burst light curve showed several peaks spaced by 7.2 min, resembling about 5% periodic modulation of the overall light curve profile.
- The periodicity in the light curve can be identified either with Kepler orbital motion or with relativistic precession of an accretion disc.
- The Keplerian period at the moment of disruption is too small ($P \approx 10$ sec) to be useful. Surprisingly, it does not depend on the BH mass.

Thus, we can conclude that the periodicity in the light curve can be identified with relativistic precession of an accretion disc. This effect has no analogue in classical mechanics. The precession in the coordinate system at rest is given by [6]

$$\Delta\varphi = 3\pi GM_{BH}/c^2 R_p \quad (6)$$

This equation was lacking to evaluate the BH mass. Why we use relativistic precession? Even moderate eccentricity value of the debris orbit is sufficient to account for modulation of the burst light curve due to lack of symmetry.

Finally we may evaluate the BH mass of $\sim 10^3 M_\odot$. The gravitational radius of the BH is about 1800 km. The size of an accretion disc equal to the tidal disruption radius is 32.6 times greater.

6 Conclusion

- GRB050922C may result from tidal disruption of a white dwarf star by a massive black hole.

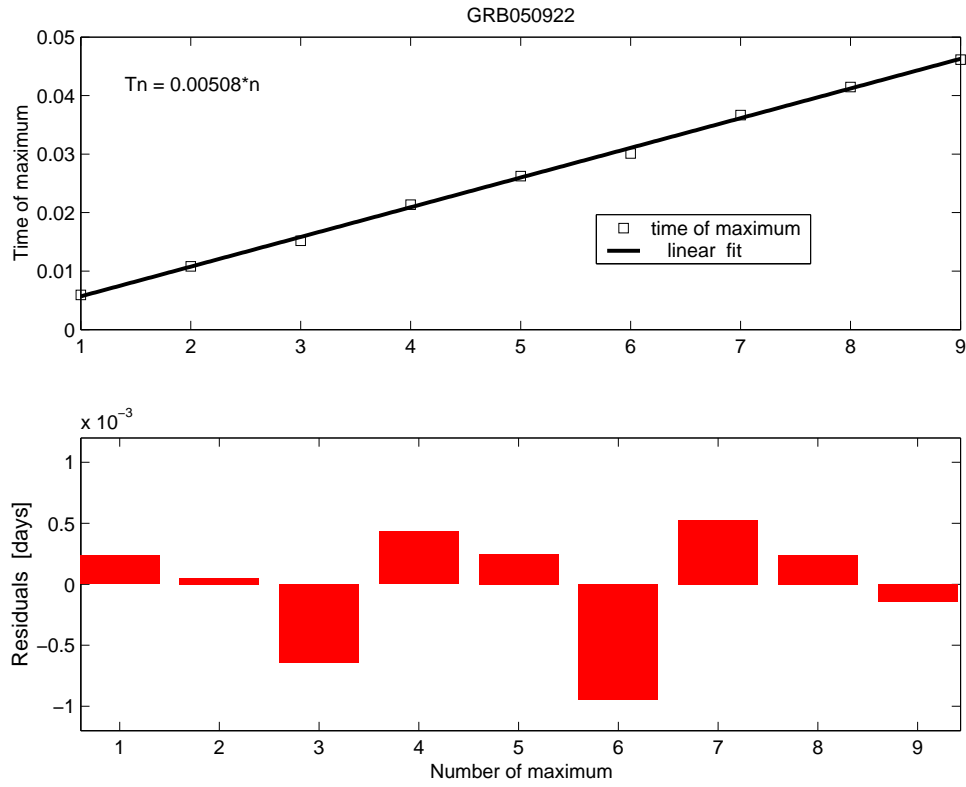


Figure 7: The harmonic period of 0.0050 ± 0.0003 d follows from the linear fit of the maximum coordinates measurements shown in Fig 6.

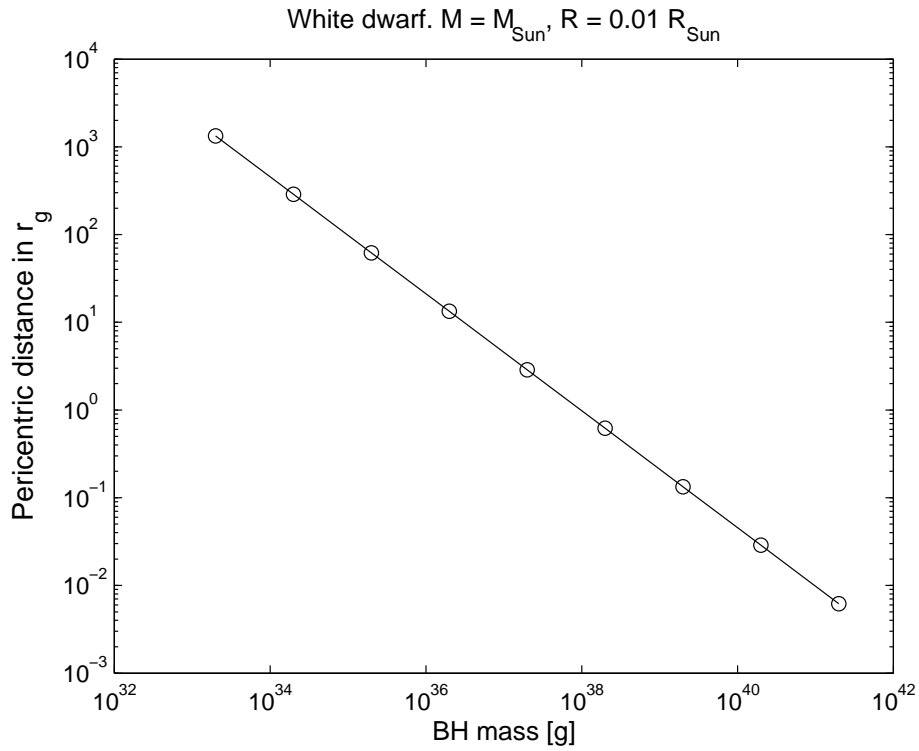


Figure 8: See text

- We may conclude that the GRB050922C optical afterglow confirms the existence of an intermediate mass black hole, of about one thousand solar mass.
- The periodicity in the light curve can be identified with relativistic precession of an accretion disc.
- Both the energy release ($E_{iso} \sim 8 \cdot 10^{52}$ erg) and the estimate of the burst event dynamical time scale (some seconds) agree closely with the model of the tidal disruption of a white dwarf star by a massive black hole.

References

- [1] *P. Jakobsson, J. P. U. Fynbo, C. Ledoux, et al.* 2006, *Astron. Astrophys.* 460, L13-L17
- [2] *Andreev M.V., et al.* GCN 4016
- [3] The GRB050922C light curve from HETE: <http://space.mit.edu/HETE/Bursts/GRB050922C/GCN-LCs-U11658.dat>
- [4] *C.R. Evans and C.S. Kochanek* 1989, *ApJ*, 346, L13-L16
- [5] *Torrence, C. & Compo, G. P.* 1998, A Practical Guide to Wavelet Analysis. Bulletin of the American Meteorological Society, Vol. 79, No 1, 61-78
- [6] *C.W. Misner, K.S. Thorne, J.A. Wheeler* 1973, *Gravitation*, W.H. Freeman and Company, San Francisco 1973, Vol. 3